THE EFFECT OF LOWER LIMB TRAINING ON MUSCULAR SUPPORT OF THE KNEE AND RISK OF ANTERIOR CRUCIATE LIGAMENT INJURY.

Jodie Cochrane[1], David Lloyd[1], Timothy Ackland[1], Thor Besier[1, 2], Bruce Elliott[1]

[1]School of Human Movement and Exercise Science, University of Western Australia

[2]Department of Mechanical Engineering, Stanford University.

An intervention study was performed to investigate the effect of lower-limb training programs on knee muscle activation patterns and their potential to support the knee load during running and cutting manoeuvres. It is known that balance training can reduce ACL injury but the underlying mechanisms are unknown. The effects that strength training has on support for the knee joint during sporting manoeuvres are also not known. Analysis of activation levels and patterns of leg muscles during running, sidestepping and crossover-cutting manoeuvres prior to and following 12-week training programs revealed important results in terms of potential support of load on the ACL. Balance training increased co-contraction and supportive muscle activation patterns, as did the combination of machine and balance training to a lesser extent. The strength training programs tended to reduce co-contraction and were associated with changes which would lead to less stability of the knee during sporting manoeuvres. It is recommended that balance training should be implemented to reduce an athlete's risk of ACL injury.

KEY WORDS: EMG, sidestepping, activation, balance, strength, prevention, ACL.

INTRODUCTION: The number of anterior cruciate ligament (ACL) injuries in sport is approaching epidemic proportions. It accounts for nearly 50% of all sporting injuries in the clinical practise (Olson, 1997). The majority of ACL injuries are non-contact, occurring mainly in sidestepping manoeuvres (Ryder *et al.*, 1997). ACL failure occurs when it gets highly loaded, thus to minimise this risk we need to reduce the ligament load by improving the muscle activation or pattern of activation to help support the load.

Despite our understanding that muscles have the ability to protect the knee ligaments, we know little about the consequential effects of training programs. Research examining *balance training* found that the incidences of ACL injury were significantly reduced following thus training type (Caraffa *et al.*, 1996). However, no definitive understanding exists on the mechanisms that underlie these changes. Research suggests that the lower risk to ACL injury maybe due to better coordination of muscles i.e. co-contraction or selective activation, resulting from improved proprioception and/or stimulation of ligamentous/muscular protective response that may occur during balance training. Contrary to this, flexion/extension strength training (Carolan and Cafarelli, 1992) decreases co-contraction with greater co-ordination of agonist muscles. This reduced co-contraction may diminish the activation patterns needed to protect the knee ligaments in sporting manoeuvres.

The purpose of this study was to identify the effects different training interventions have on muscle activation patterns surrounding the knee joint during sporting manoeuvres and their potential to reduce loading on the ACL. It was hypothesised that balance training would improve muscular support through co-contraction or selective muscle activation; whereas free weights and machine weights training would decrease muscle co-contraction and support for knee loading; and the effects of machine weights training and balance training would counteract each other.

METHOD: Fifty healthy subjects participated in this study and were randomly assigned to a control group, or one of four training groups: 1) Machine weights strength training only – using pin-loaded isotonic resistance machines for leg curl and leg press exercises; 2) Free weight strength training only – employing leg curl and squat exercises with free weights; 3) Balance training only – balance exercises using equipment such as wobble boards, tilt boards, mini trampolines, dura discs and Swiss balls; and 4) Machine weights strength + balance training – using the machine-based exercises as in machine weights group, and balance exercises as in the balance training group. All training groups were matched for training volume and intensity (12 weeks; three times per week).

This study comprised testing prior to and following the 12 week training programs. Kinematic and kinetic variables, and muscle activation patterns were obtained for each subject whilst performing running and cutting manoeuvres. The activation variables analysed included: the average activation of the flexor, extensor, medial and lateral muscles; biceps femoris/semimembranosus ratio (BIFEM/SEMIMEM); flexor/extensor co-contraction ratios (FECCR)*;* medial/lateral co-contraction ratio (MLCCR); flexor/extensor co-contraction index (FECCI) and medial/lateral co-contraction index (MLCCI) calculated to take into account the average level of activation and co-contraction.

Muscle activations were normalised to the run task as per Besier et al (Besier *et al.*, 2003). The data from the manoeuvre trials were examined in four phases of the gait: Pre-contact (**PC**)- from 60ms prior to contact; Weight Acceptance Phase (**WA**)- from heelstrike to the beginning of the main knee power absorption; Absorption phase (**ABSP**)- from the start of knee power absorption to the end of knee power absorption; and Peak Push-off phase (**PPO**)- the time corresponding to 10% of stance phase taken either side of the peak ground reaction force.

The influence of training on muscle activation patterns during each manoeuvre performed was determined using repeated measures analysis of variance (ANOVA). LSD post hoc analysis was also performed and the significance level set at $p<0.05$.

RESULTS: The balance group had significant increases in the FECCR (figure 1) with changes from pre to post-testing being as much as 18% in the S60 manoeuvre. Significant increases were also observed following this training program in flexor muscle activation (figure 3), BIFEM/SEMIMEM (figure 4) and MLCCR, and significant decreases in the quadriceps muscles activation (figure 2). The free weights and machine weights training groups both experienced decreases in the FECCR and FECCI, contributed to by significantly increased levels of quadriceps activation (figure 1 & 2). The free weight group also experienced a decrease in the level of hamstrings activation of ~14% in the stance phases of the manoeuvres (figure 3). The machine weight training group experienced significant increases in MLCCR and MLCCI, whereas the free weights group had a significant improvement in the BIFEM/SEMIM ratio (figure 4). The machine/balance group displayed significant decreases in the FECCR, but there were significant increases in the MLCCR following training by as much as 12.2%. An increase in extensor muscle group activation was observed, and decreases in the flexor activation in all phases of the manoeuvres (figure 2 & 3). The BIFEM/SEMIMEM also rose significantly (figure 4).

DISCUSSION: This study aimed to identify if muscle activation changes, subsequent to training programs, would be revealed in the performance of sporting manoeuvres and if these changes had the potential to alter ACL loading. The different training types had varying effects on muscle activation patterns used following implementation of the programs, with all supporting the respective hypotheses to some extent.

Balance training resulted in increased generalised co-contraction, directed co-contraction (selective activation) and also provided support of pre-programming during the performance of the manoeuvres. An increase in FECCR was observed as a result of decreasing quadriceps, and increasing hamstring activation. The increase in hamstring activation is of importance given it can resist anterior tibial translation, thereby reducing ACL loading (Cross, 1996). Furthermore, studies have demonstrated that hamstring activation, co-contracting with the quadriceps muscles, decreases the ACL loading and reduces the range of knee flexion over which the ACL is loaded (Ohkoshi *et al.*, 1991; O'Connor, 1993). In addition, a decrease in quadriceps activation may reduce ACL risk of injury, especially at extended knee angles such as occur during the WA phase, where the quadriceps can cause anterior tibial translation (Li *et al.*, 1999). The increases in co-contraction can also support external varus/valgus moments possibly reducing ACL load (Lloyd and Buchanan, 2001). Favourable changes also occurred in BIFEM/SEMIMEM, with a high ratio being suggested to improve ability of the biceps femoris to resist the internal rotation loading produced in sidestepping tasks (Besier *et al.*, 2001), and thus affords protection to the ACL.

Results for the machine weights and free weights training groups supported the hypothesis that strength training would decrease co-contraction when executing manoeuvres. Studies have indicated that the reduction of co-contraction may diminish the activation patterns needed to protect the ligaments of the knee (Baratta *et al.*, 1988; Lloyd and Buchanan, 2001). It was thought that the free weights group would use more quadriceps and hamstring co-activation to perform the manoeuvres post training compared to the machine weights group, due to greater stabilisation requirements associated with the free weights training. However, this did not occur, and results concurred with previous findings where the strength training resulted in better coordination and activation of the prime movers and decreased levels of co-contraction (Rutherford and Jones, 1986).

The machine/balance training experienced muscle activation changes influenced and experienced by the both types of training. Overall there were more favourable changes with improvements in MLCCR and medial/lateral selective activation, which is ideal for support of varus/valgus loading (Lloyd and Buchanan, 2001).

CONCLUSION: The results showed that the balance training elicited favorable activation patterns following intervention, as did the machine/balance training to a lesser extent. The strength training programs were associated with changes in muscular activation which would lead to less stability of the knee during sporting manoeuvres. In terms of applicable results from training, it is recommended that balance training be implemented to reduce athlete's potential risk of ACL injury.

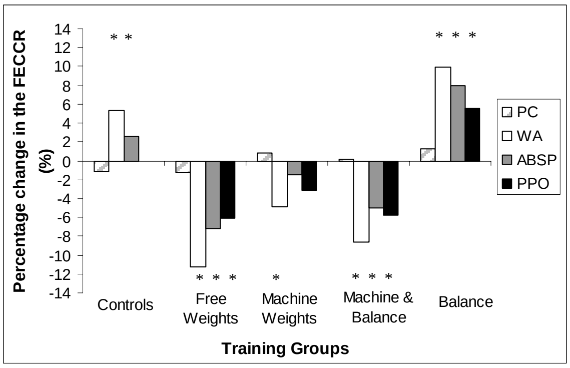

Figure 1. Percentage change in the FECCR across all manoeuvres for each training group following post-testing of all manoeuvres during each phase. *p<0.05.

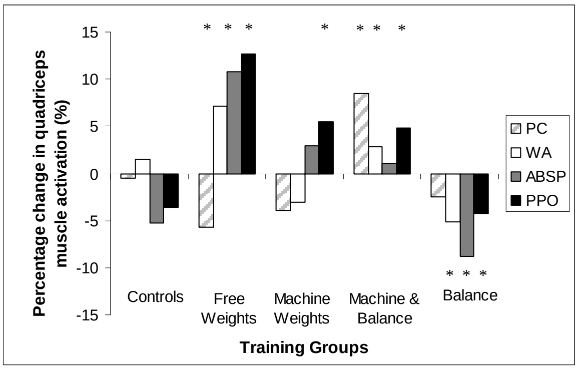

Figure 2. Percentage change in quadriceps muscles activation from pre-testing to post-testing of all manoeuvres during each phase following each training type. *p<0.05.

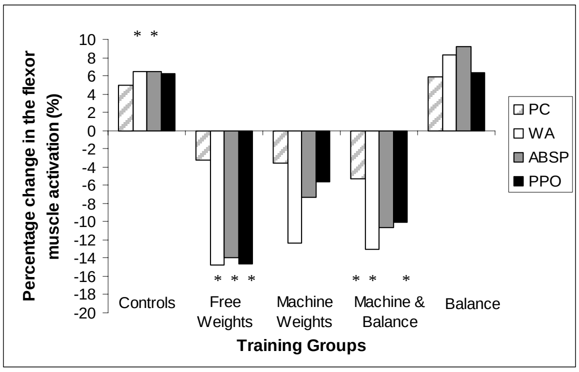

Figure 3. Percentage change in flexor muscles activation from pre-testing to post-testing of all manoeuvres during each phase following each training type. *p<0.05.

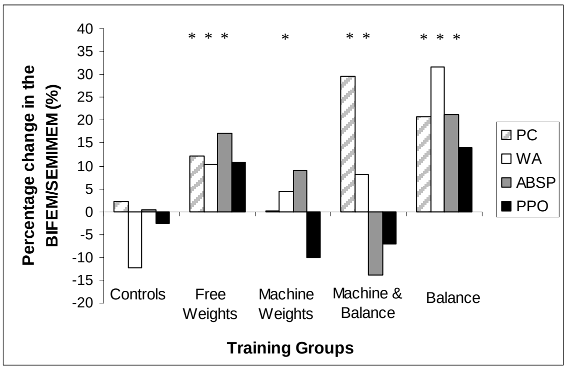

Figure 4. Percentage change in BIFEM/SEMIMEM from pre-testing to post-testing for each training group during each phase of the combined manoeuvres. *p<0.05.

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